INTEGRATING USER-BEHAVIOUR AS PERFORMANCE CRITERIA IN CONCEPTUAL PARAMETRIC DESIGN

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Abstract. Prediction of user behaviour has always been problematic in architectural design. Several methods have already been developed and explored to model human behaviour in architecture. However, the majority of these methods are implemented during post-design evaluation where the insights obtained can only be implemented in a limited capacity. There is an apparent gap and opportunity, in current research and practice, to embed behaviour simulations directly into the conceptual design process. The proposed paper (research) aims to fill this gap. This paper will report on the results of a recently completed research exploring the integration process of Agent Based Modelling into the conceptual design process, using a parametric design approach. The research resulted in the development of a methodological framework for the integration of behavioural parameters into the explorative stages of the early design process. This paper also offers a categorisation and critical evaluation of existing Agent Based Modelling applications in current research and practice, which leads to the formulation of possible pathways for future implementation.

Keywords. Performance Based Design; Generative Design; Behaviour Modelling; Agent Based Modelling; Parametric Design.

1. INTRODUCTION

There is a growing area of interest among designers and design researchers which perceive the ultimate objective of design as “to create form that satisfies behaviour” (Moore 1979, p.53). This has been reflected in the work of various architects and urban planners, as Dijkstra and Timmermans (2002) affirm, where the designers have been keen to determine the effect of their designs on the behaviour of users. However, despite this keen interest on the link between “design, form and its users” in the built environment, Yan and Kalay (2005) observed that majority of simulations that are created in early stages of design focus on understanding the physical qualities (like lighting or energy use) rather than user behaviour. And those that simulate behaviour are generated to “evaluate” the performance during the late stages of the design process with little room to make changes in design decisions which may also cause investment into poorly performing design
solutions (Turrin, Von Bluelow and Stouffs 2011). The research that is reported in this paper addresses the gap between (user) behaviour simulations and the conceptual design process.

Integration of performance assessment into the generative design process is commonly referred to as ‘Performance Based Generative Design’. In this research, Parametric Design (PD), which is based on constructing parameters and building relationships between those parameters, will be used as the Generative Mechanism to drive a performance-driven design process. The performance that is assessed, in this particular design research, is the user behaviour. We employ Agent Based Modelling (ABM) as an approach to integrate ‘behaviour-based performance’ with ‘generative design’ in design-led research. And to that end, we develop a practical and methodological design framework that aims to bridge the aforementioned gap. It is envisaged that the proposed methodological design framework will provide an opportunity for designers to set behaviour-related objectives into their designs and explore the effectiveness of their proposed solution alternatives.

The paper will continue with presenting a concise background of ABM and the categorisation of existing approaches of ABM in architecture literature. In the following section, the paper will present the research approach and methodology (Research by Design) which will lead to the formulations and descriptions of two design experiments and the iterative development of Design Methodological Framework (DMF). The final section will present the findings and reflections on this research.

2. AGENT BASED MODELLING

According to Parascho et al. (2013 p.238), “Agent models rely on the definition of a global system through its simple part, a so-called agent”. Based on defined rules, agents are in interaction with other agents and show complexity and emergent behaviour (Reynolds 1999, cited in Parascho et al. 2013). ABM should be utilised where agents have the potential to behave differently and the simulation results are affected by this variety. The built environment provides a complex context which involves various forms of interactions between humans and the built ecosystem, and thereby, ABM can be considered as a potent tool to implement in this context. Various past studies have used ABM as a behaviour modelling tool in architectural design; mostly used for evaluation and visualisation purposes and predominantly applied in later stages of design - although there are few studies try to integrate human behaviour in design (Hong, Schaumann and Kalay 2016). However, ABM carries enormous potential to be used as a decision-making tool in the design process. In this research, ABM has been employed to simulate user behaviour in early design stages. And in this regard, we aim to contribute to the existing knowledge and discussion by developing DMF that integrates Performance Based Generative Design, and ABM. And to that end, we introduce a new approach towards the formulation of ‘Behaviour-Based Parametric Design’.
3. ABM IN ARCHITECTURAL DESIGN: CATEGORISATION OF EXISTING APPROACHES

A thorough survey of the past and recent works in architecture field has revealed the following use categories, based on the different perceptions and uses of ABM - either as a methodology or as a tool - and in support of the varying intentions of the designers.

The first one, ‘Design Aid’ approach, is whereby agents are seen as software or software components, can be divided into two sub-categories; a) communicative and b) generative. In Communicative Approach, agents are seen as computer systems and their role is to enhance communication. For example, Pinho et al. (2006) developed an agent framework called SYMBAD (Similarity Based Agents for Design) for improving process awareness in an architectural design firm by capturing and categorising information communicated between team members. In Generative Approach, ABM is used as a generative system, and agents have the role of a computational tool. For instance, Gerber, Pantazis and Wang (2017) generated various types of agent systems and developed a design with autonomous agents that act according to the given rules which define possible interactions.

The second approach, ‘Evaluative Approach’, is used to simulate the behaviour of users (agents) of a particular product or space. The simulation helps to foresee the use of that product or space in a virtual environment and make improvements to design accordingly. Dijkstra and Timmermans (2002) developed a model using ABM to simulate shopping behaviour. Similarly, Schaumann et al. (2016) proposed a framework to simulate events and generate a representation of the time-based use of a complex environment.

The third one is the ‘Formative Approach’. In this approach, the design elements are seen as agents, and the designer defines agents and creates relationships between them. The design elements act according to the defined rules and relationships with other agents and the environment. Thus, the designer tries to achieve the fittest design scheme using design elements. One of the first studies in this approach belongs to Krause (1997). Krause’s work was based on the intelligence and design sensibility of the architectural objects. Guo and Li (2017) also used this approach to define topological solutions for their designs. They used agents as design elements and created ABM with these agents together with the basic relationships and the rules that define agents’ position.

ABM approach we propose in this research considers agents as humans, have a role to simulate human behaviours, and specifically aims the early design process. From this perspective, for the purpose of this research, the ‘Evaluative Approach’ of ABM has been identified as the best fit.

4. RESEARCH APPROACH AND METHODOLOGY

In this study, we have followed a mixed methodology that adopts Research by Design (RbD), which is different from both qualitative and quantitative models, enabling design to become more than a problem-solving exercise, which creates new questions and solutions (Kocaturk, Biggs and Koeck 2014). The concept of RbD can be grounded on Frayling’s (1993) second category
of research; ‘research through design’. RbD is also known as design-led research, and more broadly as practice-based research, is a trans-disciplinary and methodologically distinct approach to knowledge production, which involves “knowing through making”. Its distinct methodology aims to discover and create new knowledge, through creative inquiry, for the development of new designs, products, processes, and systems. As an output of this research, we developed a new Design Methodological Framework (DMF) as a practical guideline to facilitate ‘Behaviour-Based Parametric Design’. This requires a clear methodological framework to understand which steps to take before implementing the iterations to generate design alternatives. We have devised a design experiment to develop and test such a framework through the adoption of RbD methodology. Reflective observation of the steps that are taken within the natural flow of the design process in the design experiments led to the development of DMF. The proposed DMF specifically focuses on the integration of ABMS (Agent Based Model Simulations) into the PD process. And to that end, the proposed DMF is intended to provide a practical guideline for designers and researchers to integrate behaviour based information into the early design processes.

5. DESIGN EXPERIMENTS

5.1. EXPLANATION OF THE DESIGN EXPERIMENTS

The design challenge was set as the placement of 6 activity spaces in a fun fair park, within an imaginary site (Figure 1, Left), which was decided according to specific behaviour-related design objectives. Although the success of the design experiments in achieving these objectives was important, the design-research challenge was the integration of behaviour-based information into the conceptual design process. For the two experiments, two behaviour-related design objectives were set, and specific configurations for each of them were created.

For the first experiment, the design objective was set as ‘equalising the distribution of users’ which referred to the creation of a design solution in which people are equally distributed through the whole site in order avoid localised crowding on site, and thus, creating better user experience. For the second experiment, the behaviour based objective was ‘increasing the quality of experience’, which referred to the creation of activity spaces that are in equal quality with regard to user density. In the first experiment, the initial data was gained from the ABMS of the site while in the second experiment, it was gained from ABMS of random configurations in order to support the applicability of DMF on both creation and development of conceptual design projects.
The human agents used in the behaviour simulations were autonomous, were able to interact with other agents, and defined as reactive, and goal-directed. The environment (site) affected agents’ actions according to the agent’s own and other agents’ locations. The environment in the experiments was rather static and did not change/evolve with the simulation. Instead, the change/evolution was carried out in the respective PD environment. The software used for the PD was Grasshopper while the software used for ABMS was MassMotion, an advanced crowd simulation software (Figure 1, Middle and Right).

5.2. DESIGN EXPERIMENT 1: EQUALISING THE DISTRIBUTION OF USERS

In the first experiment, we initially aimed to develop an understanding of the distribution of users within the site. It was assumed that placing activity spaces to areas away from the main user paths would create a more equalised distribution of users. In order to define main user paths and empty spaces, movements of agents were tracked with ABMS (Figure 2, Left and Middle) and the ‘Agent Count Map’, showing the agent density of the site, was created (Figure 2, Right). In order to translate colour codes to usable data, a point cloud was created and superposed onto the ‘Agent Count Map’ in PD. In this way, each point gained value from 0 to 10 according to its colour equivalent, from white to red. Thus, the necessary data to locate activity spaces was created.
The configuration of the 6 activity spaces would be decided according to the empty areas (defined by the enclosing pathways). Therefore, the points that had the lowest value according to the colour code (white areas in the map) were selected and used to define the enclosed areas. The biggest enclosed areas were selected as the places of activity spaces and thereby ‘empty space configuration’ was created (Figure 3, Top). In order to test and compare this configuration, one opposite and 5 random configurations were created. The opposite configuration (on path configuration) was created by placing the activity spaces on user paths which were determined by selecting the points that had the highest value (the points correspond to red, orange and yellow areas) (Figure 3, Middle). The configurations created by random operations (in PD) were defined as ‘random configurations’ (Figure 3, Bottom).

All configurations were transferred to ABMS to create new ‘Agent Count Maps’ for each to compare the level of equalised distribution they provided (Figure 4). Well-equalised distribution meant that the percentage of empty space (0 people or white colour), should be kept minimal. At the same time, the percentage of 0-10 people (dark blue colour) to 50+ people (red colour) should be decreased to avoid crowded areas.

The line graph above was created to show the distribution levels of users in each configuration (Figure 5). As depicted in the figure, the ‘empty space configuration’ (green line) has minimum 0 people while the ‘on path configuration’ (blue line) has the maximum 0 people. Likewise, the ‘empty space configuration’ has maximum 0-10 people percentage while the ‘on path configuration’ has the minimum. The random configurations are in between these two. Different from expected, the percentage of 50+ people in configurations are diverse. Although the ‘empty space
configuration’ does not show the optimum scenario, it is the closest to an optimum than any other configuration. Hence, the ‘empty spaces configuration’ shows the most suitable condition while the ‘on path configuration’ shows the least suitable in terms of equalised distribution of users among all configurations. As a result, ‘empty space configuration’ showed the best performance in responding to the initial objective.

5.3. DESIGN EXPERIMENT 2: INCREASING THE QUALITY OF EXPERIENCE

In the second experiment, it was assumed that when users have ease of access to an activity space, more visitors will prefer to use that activity space. If the locations of activity spaces are arranged within a similar range of accessibility, the difference between the number of visitors of activity spaces will be decreased. This will result in less crowding and equalised use of activity spaces. In order to achieve this, five different random configurations (created in the first experiment) were put in the ABMS and ‘Agent Count Maps’ (together with the number of users) were created (Figure 6, Top). As a next step, several distance variables were tested to understand the main factor that affects the number of visitors. ‘Average distance to entrances’, ‘weighted average distance to entrances’, ‘average distance to activities’ were obtained for each activity space and for five configurations (Figure 7).

To see the main determinant distance value that affects the number of users, the ‘Pearson’s Correlation Analysis’ was carried out. The value that has a higher correlation with the number of users would be selected. It was seen that there is a strongly confidential ‘very large negative correlation’ between the ‘weighted average distance to entrances’ and the number of users (‘weighted average distance to entrances’, r:-0.752, p:0.00; ‘average distance to entrances’, r:-0.663, p:0.00; ‘average distance to activities’, r:0.182, p:0.335) (Cohen 1988, Clegg 1982). Thus, the main factor that determines the number of agents was identified as
the ‘weighted average distance to entrances’. To decrease the gap between the number of users in activities, the possible number of users at each point of the site should be identified. Therefore, ‘Linear Regression Analysis’ was carried out using ‘weighted average distance to entrances’ and the possible number of agents for each point was identified.

In the following step in PD, the obtained numbers were converted into a scale between 0-100. Then, colour maps were generated to illustrate the level of the potential number of visitors each point would attract. After that, the centres of activity spaces were moved to the closest points that are in the range between 25-75, while keeping distance to other activities - minimum 20√2 meters - and the boundaries - minimum 2 meters - (Figure 6, Middle). The new configurations were then transferred back into ABMS to find out the number of visitors in each new configuration (Figure 6, Bottom).

Table 1. Mean and Standard Deviation of Initial and Final Configurations.

<table>
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<tr>
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<th>MEAN</th>
<th>STANDARD DEVIATION</th>
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<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Final</td>
</tr>
<tr>
<td>Random1</td>
<td>120.2</td>
<td>119.2</td>
</tr>
<tr>
<td>Random2</td>
<td>121.5</td>
<td>118.5</td>
</tr>
<tr>
<td>Random3</td>
<td>118.0</td>
<td>121.2</td>
</tr>
<tr>
<td>Random4</td>
<td>118.3</td>
<td>118.8</td>
</tr>
<tr>
<td>Random5</td>
<td>117</td>
<td>118.3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>119.0</td>
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It was expected that for each new configuration, the number of visitors for each activity space would get closer to the average. ‘Mean Analysis’ was carried out for each of the five different configurations to get mean and standard deviation values (Table 1). Moreover, to compare the mean and standard deviation values of the initial and final results, ‘Paired T-Test’ was carried out. It was seen that there is a confidential decrease in the standard deviation values for all configurations (Mean: 2.060, p:0.02) while there is not a significant change in the mean values. This means that there is a decrease in the gap between the number of visitors across activity spaces. Thus, the aim of this design experiment, which was to increase the quality of user experience through improving the ease of access to activity areas was achieved.
6. THE PROPOSED DESIGN METHODOLOGICAL FRAMEWORK

The main aim of this research was to explore the integration of behaviour-based information into the conceptual design process to provide the necessary data to structure DMF. The simulation results from the ABMS were converted to data and used as variables in the PD. Then, the results were put back into the evaluative ABM once again to compare the results. In this way, the behaviour-based information was integrated into the conceptual design process to explore alternative configurations and their consequences for the two experiments (Figure 8, Left and Middle). The structure of DMF is based on the iteration steps between Evaluative ABM and PD. While the evaluative ABM was utilised for the user simulations, PD was employed as a platform to manipulate the form according to these simulation results (as input). The below diagram (Figure 8, Right) is the combined representation of DMF that has been formulated through the design experiments. In the proposed DMF, the iterations start with integration of site or design input into the behaviour simulations. The system continues with the integration of the preliminary results to the parametric environment. The iteration steps, the loop, between PD and Behaviour Simulations could continue until the design outcome is satisfactory in terms of behaviour related objective(s).

7. CONCLUSION

This research aimed to explore the integration process of behaviour-based information of users (in the built environment) into the conceptual design process to achieve behaviour-related design objectives. For this reason, the concept of ABM (Agent Based Modelling) and the various approaches associated with ABM were investigated. Through employment of Performance Based Generative Design and ABM, DMF (Design Methodological Framework) had been developed. It is important to note some of the limitations of this study with possible implications on the final outcome. Firstly, the design objectives were limited to behaviour based parameters only and in a very focused context. In actual fact, a design has various objectives and is not limited to only behavioural objectives of the users. Secondly, during the design experiments, simulation results had to be manually transferred to the PD (Parametric Design) environment which may have
resulted in loss of data. Likewise, the instances had to be transferred to the
ABM environment and manipulated manually to make simulations although they
could have been generated easily through PD. This highlights another limitation
beyond this research which rather relates to the interoperability issues between
the existing commercial PD and ABM software. It is anticipated that this study
could create a greater awareness of user behaviour among designers and provides
useful guidelines (through the proposed DMF). This study can be expanded in
the future with multiple behaviour-related design objectives which may result in
further improvements to the proposed DMF.

References
Cambridge University Press.
LEA Lawrence Erilhaum Associates Publishers.
user behavior to support the assessment of design performance, Automation in construction, 11(2), 135-145.
Frayling, C.: 1993, Research in art and design, Royal College of Art Research Papers 1, 1, 1-5.
architecture: Design exploring geometry, user, and environmental agencies in façades,
Automation in Construction, 76, 45-58.
Guo, Z. and Li, B.: 2017, Evolutionary Approach for Spatial Architecture Layout Design
Hong, S.W., Schaumann, D. and Kalay, Y.E.: 2016, Human behavior simulation in architectural
design projects: An observational study in an academic course, Computers, Environment
and Urban Systems, 60, 1-11.
and [un] desirable design futures, Architectural Design Research Symposium 2014, Victoria
University of Wellington.
Planning, eCAADe 2013: Computation and Performance Proceedings of the 31st
International Conference on Education and research in Computer Aided Architectural
Design in Europe.
Schaumann, D., Morad, M.G., Zinger, E., Pilosof, N.P., Sophier, H., Brodetschi, M., Date, K. and
Kalay, Y.E.: 2016, A Computational Framework to Simulate Human Spatial Behavior in
Built Environments, SimAUD 2016 Symposium on Simulation for Architecture and Urban
Design.
Geometry in Architectural Design Using Parametric Modeling and Genetic Algorithms,
Advanced Engineering Informatics, 25(4), 656-675.
Yan, W. and Kalay, Y.: 2005, Simulating Human Behaviour in Built Environments,
Proceedings of CAAD Futures, 301-310.